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DEVELOPMENT OF A MEDIUM ENERGY MODULATED ELECTRON GUN FOR ORBITAL EXPERIMENTS

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Rome Laboratory has provided funding support for the development of a medium powered modulated electron gun to be flight tested on a NASA sounding rocket designated CHARGE-2B. The objective of the flight test was to study both the generation and the propagation of VLF electromagnetic waves in the near and far fields of the waves.

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Modulated electron gun (MEG) Development and Flight

Background

Rome Laboratory has provided funding support for the development of a medium powered modulated electron gun (MEG) to be flight tested on a NASA sounding rocket designated CHARGE-2B. The objective of the flight test was to study both the generation and the propagation of VLF electromagnetic waves in the near and far fields of the waves.

The purpose of this contract is to provide funding for more extensive tests on the MEG systems to assess the feasibility of incorporating the design as part of an orbital payload to provide more scope for studying the dependence of the generation and propagation of waves from a modulated electron beam than is possible with the limited location and duration of a sounding rocket flight.

MEG

Mechanical configuration

The mechanical configuration of the MEG consists of a 24 inch long section of 17 inch diameter payload skin hermetically sealed by bulkheads at each end. In order to allow the routing of cables connecting other elements of the payload, a chord of the MEG cylindrical enclosure was formed by an additional bulkhead running lengthwise, and separating the inner sealed part of the enclosure from the vented cable-run. The sealed portion of the MEG section was designed to retain its fill of dry air at atmospheric pressure during the flight to avoid the possibility of incomplete venting and consequent arcing of HV elements. The beam emission port of the electron gun projected through a sealed penetration in the vertical bulkhead to enable the electrons to be emitted perpendicular to the longitudinal axis of the payload after an outer door in the payload skin had been deployed. Details of the overall mechanical configuration are shown in figure 1.

Internally, the mechanical structure consisted of three main elements; the electron optics of the electron gun, shown in figure 2; the HV power supply made up of ten 300 volt batteries of NiCd rechargeable cells; and the sub structure which provided support for the filament power supply, the modulator power amplifier, and the signal condition and opto-isolator units.

Electrical configuration

A schematic block diagram of the electrical configuration of the MEG is shown in figure 3. The power supply to heat the filament is an electrically isolated converter providing ac power at 18 volts and 5 amps to the filament from the prime 28V payload power. The accelerating potential for the electrons emitted by the MEG is derived from a 3kV rechargeable battery pack. The battery is comprised of ten 300V packs connected in series by ten relays operated by a common control signal. In addition to the individual relay control, an additional relay is incorporated to isolate the complete 3kV battery. The HV system includes an overcurrent sensor which disconnects the battery by opening the ten individual relays connected to the 300V battery packs. The overcurrent sensor is configured to provide a delay of 0.5 sec in restoring the accelerating potential in the event of an arc during flight operations. The system has been tested against a short circuit across the 3kV supply and shown to be capable of surviving this condition without either internal or external damage.

The modulating voltage to control the beam current is amplified to the correct level of close to 3kV by a vacuum tube amplifier mounted in the MEG enclosure. The amplifier is a class A common grid gain stage and cathode follower output stage using two Varian type 8873 power grid triode vacuum tubes. For the CHARGE-2B application, the signal for the modulation amplifier was derived from a frequency synthesizer which generated a

waveform calculated to result in a sinusoidal variation of beam current after being modified by the transfer characteristic of the electron gun.

The remainder of the electronics in the MEG consists of signal conditioners and opto-isolators to process the housekeeping and electron gun data and control signals for safe communication to the outside of the HV MEG enclosure.

Fabrication and Testing

Early in the contract production designs were finalized, and fabrication of the various elements of the two MEGs was competed and tested at the subsystem level. One of the MEG skins was received from Wallops Flight Facility (WFF) and the internal sealed bulkheads were attached to the skin by an epoxy adhesive. The integrated structure was returned to WFF for bending tests needed to characterize the asymmetry in stiffness of the MEG section introduced by the vertical sealed bulkhead.

The electron optical assembly was tested in a vacuum chamber by mounting the assembly to a bulkhead on the chamber and connecting the externally mounted laboratory power supplies. The current and waveform of the modulated beam was monitored by the flight Rogowski coil mounted at the electron beam exit port. The current voltage characteristics of the MEG were determined to provide data to determine the filament current necessary to raise the filament temperature to a value which would result in the planned maximum emission current of 1 amp at the 3kV accelerating potential. The current voltage characteristic of the MEG tested is shown in figure 4.

Following the vacuum testing of the electron optics and the return of the MEG structure to Utah State University (USU), the system components were installed in the MEG "can" and the assembled unit was tested electrically using a dummy load to represent the currents drawn by the filament and electron beam of the MEG.

The MEG beam current monitors used signals from the Rogowski coils. The positive and negative signals corresponding to beam-on and beam-off, respectively, were processed by logarithmic amplifiers, and the peak signals between telemetry samples were returned. The calibration coefficients to convert the telemetry data to engineering units are shown below in table 1.

Table 1

	Mnemonic	Description	Eng. Units	A0	A1
MEG1					
	BCM+1	Beam current, positive	Amperes	4.700	1.1627
	BCM-1	Beam current, negative	Amperes	4.700	1.1073
MEG2					
	BCM+2	Beam current, positive	Amperes	4.700	1.1627
	BCM-2	Beam current, negative	Amperes	4.700	1.1073

Table 1: Calibrations for the MEG beam current channels expressed as Eng. unit = +/- $2 \cdot 10^{((TM-A0)/A1)}$ where TM is the conditioned 0-5V signal output to the telêmetry

The housekeeping channels of the MEGs were calibrated, and the calibration coefficients to convert the data transmitted in the telemetry stream to engineering values are as listed in table 2 below:

Table 2

	Mnemonic	Description	Eng. Units	A0	A1
MEG1					
	MEG1HV	Battery Voltag	Volts	0.0	1000.0
	MEG1IPCO	Isol. Pwr Conv. Cur.	Amperes	0.0	6.00
	MEG1FOCI	Focus Coil Current	Amperes	-0.514	0.966
	MEG1FILI	Fil. Pwr. Conv. Cur.	Amperes	0.0	2.00
	MEG1AN1I	Anode1 Current	Amperes	0.0	0.10
	MEG1BATI	HV Battery Current	Amperes	0.0	0.40
	MEG1PRES	Internal Pressure	lbs/sq-in	-1.875	3.750
MEG2					
	MEG2HV	Battery Voltage	Volts	0.0	1000.0
	MEG2IPCO	Isol. Pwr Conv. Cur.	Amperes	0.0	6.00
	MEG2FOCI	Focus Coil Current	Amperes	-0.543	0.970
	MEG2FILI	Fil. Pwr. Conv. Cur.	Amperes	0.0	2.00
	MEG2AN1I	Anode1 Current	Amperes	0.0	0.10
	MEG2BATI	HV Battery Current	Amperes	0.0	0.40
	MEG2PRES	Internal Pressure	lbs/sq-in	-1.875	3.750

Table 2: Calibrations for the telemetry channels for the MEG housekeeping expressed as Eng. unit = A0 + A1*TM volts where TM is as defined in Table 1.

The electron optics assembly was attached to a port of a vacuum chamber, and the MEG was driven by the flight electronics mounted externally to the chamber. The flight Rogowski coil was mounted close to the exit port of the MEG, and it was used to monitor the beam current directly, rather than the peak beam current monitored in the flight configuration. Figure 5a shows the waveform of the current monitored by the Rogowski coil. The slight asymmetry between the upper (low current) and lower sections of the waveform arises from the flight HV batteries being used in this test at a lower than nominal voltage due to their being partially discharged. Fourier analysis of the beam current at the exit port of the MEG is plotted in figure 5b and shows a power spectrum peaking at the modulation frequency of 4471Hz with little evidence of harmonics.

Another vacuum chamber test of the MEG design was directed to determine the divergence of the beam a short distance from the MEG exit port. A sheet of aluminum was suspended in the chamber and was grounded to the chamber wall through its suspension wires. The impact of the beam caused the aluminum to be heated, and after cooling, a permanent image of the two dimensional intensity of the beam cross section at a distance of 610 mm from the exit port was visible on the aluminum sheet. A photograph of the image is shown in figure 6a, and a plot of the intensity across the image is shown in figure 6b. The photograph does not reproduce very well, but the discoloration of the aluminum is distinct enough to measure it on the plate. The intensity plot shown in figure 6b is from a

band across the center of the beam image. The arbitrary intensity scale is inverted, higher intensity being shown as a lower value. The dip in intensity in the center of the beam may be evidence of a hollow cylindrical geometry of the beam, but it is not possible to be quantitative about the effect because the original plate shows a color change in the center, and this is reproduced as an intensity change in the black and white photographic image. The width of the beam image recorded on the aluminum plate was 45 mm. Since the diameter of the MEG exit port is 22.9 mm, therefore the initial beam divergence is 2.1 degrees.

Payload integration

Following final bench tests of the MEGs they were delivered to WFF for integration with the rest of the payload in preparation for qualification bending and random and sine sweep vibration tests of the complete payload. After the installation of the electron optic units into the MEG modules, no further electrical testing of the filaments was possible when they were integrated into the payload due to the possible destruction of the filaments if they were heated to emission temperatures of 2100°C at atmospheric pressure.

Environmental tests

The environmental tests were supported by performing tests of the MEG units before and after the qualification tests to verify that the equipment suffered no damage. The MEG electron optic units were then removed to USU for final evaluation of their operating characteristics under vacuum conditions and were then shipped directly to Poker Flat Research Range (PFRR) for final installation in the payload.

Flight preparation

The build up and testing of the payload including the installation of the MEG electron optics was supported at PFRR. Also the final checks of the system during the launch countdown was monitored to confirm that the MEGs were flight ready.

Flight performance

The flight data and visual inspection of the recovered payload indicate the protective doors covering the exit apertures of the MEGs both deployed on time and correctly. The arming of the HV power supply occurred at the correct time in the sequence of events leading up to the initial emission of the MEG beams.

A survey of the total emitted current from the two MEGs is shown in figure 7 in which the emitted current in amperes is plotted against mission elapsed time for the period 100 secs to 500 secs. The step in signal at 110 secs corresponds to the switch on of the MEG power bus, and the step at 140 secs corresponds to the HV enable activation. The first beam emission in sequence 1 then occurred at 148 sec showing a peak beam emission current of about 1.6 amps. The regular pattern in the emitted currents shows the eight steps in each of the sequences of modulated beam emission. Sequence 2 shows only 7 steps because of gun arcing and shut down at the start of the sequence which corresponded to mother-daughter separation. Sequence 10 is incomplete because of MEG shutdown as the payload re-entered the denser part of the upper atmosphere below 100 km altitude. The MEG power busses were turned off at 490 secs.

Figure 7 shows that the peak emitted current was in the range 1.4 - 1.8 amps during the operational part of the flight. The low resolution survey plot is shown in higher time resolution for the 10 second period, 300-310 sec mission elapsed time (MET) in figure 8. The figure shows the separate currents from MEG1 and MEG 2 for two of the eight triads of frequencies making up one sequence. The apparent slow decay of the currents after the emission was interrupted is a consequence of ac coupling within the Rogowski coil, corresponding to a time constant of 0.2 sec

It was mentioned earlier that we detected MEG arcing after mother-daughter separation. This was due to large amounts of gas released by the daughter reaction control system to stabilize the daughter after a fairly large tip-off occurred at separation. The arc suppression worked exactly as planned by shutting the MEGs down for 0.5 sec, then restarting and again shutting down if the overcurrent condition persisted. The shutdowns occurred for a long enough time that the first triad of frequencies in sequence 2 was lost. However, after that, the daughter was far enough away that no further gas release induced MEG shutdown was seen. At re-entry the arc suppression cut in again as the atmospheric pressure reached a level too high for the MEGs to operate.

The parachute recovery system for the payload worked correctly, but the mass distribution was such that prior to parachute deployment, the mother was flying in a science section down orientation. This caused high, supersonic gas flow through the science section and the channels outside the pressurized section of the MEGs into the mother telemetry section. Friction of the gas on components in those parts of the payload raised their temperatures high enough to melt and burn plastic insulation, resulting in severe heat damage to those units. The hot gas also damaged the exposed parts of the MEG electron optics.

Visual evidence on the MEG sections indicates that the interior of the MEG sections was probably not damaged by the heat of re-entry due to its large thermal mass. However, no disassembly or testing of the interior components has been performed since there are no re-flight prospects at present.

Conclusions

The medium energy electrons guns performed well in flight and emitted modulated beams of electrons at frequencies in the VLF range. The emission current on MEG2 was lower than planned due to the electron gun operating in an emission limited state, and the filament temperature being slightly lower than it should have been. The emitted current for MEG2 was very constant, and not strongly influenced by changes in the vehicle environment. MEG1 was operating in the space charge limited state, and showed a higher current, but was subject to much greater variability in response, primarily, to gas pressure changes around the payload. If more time had been available before launch, we believe the filament temperatures and perveances could have been fine tuned to give the desired currents from each of the MEGs and with less variability in the peak emitted currents.

Control of the battery HV power supply worked very well, and it was amply demonstrated that arcs driven by such high energy power sources can readily be suppressed by the techniques used in the MEG design.

Apart from the external heat damage, the MEGs appear to have survived the flight well, and there are indications that they could be refurbished if there was a need to re-fly them. The damage they suffered was not, of course, intrinsic in the design of the MEGs, but was a consequence of the general payload assembly.

We believe that this first flight of a triode electron gun system was successful, and points to the possibility of much greater flexibility in the energy and modulation waveform capability for space borne electron guns than was possible with earlier diode designs.

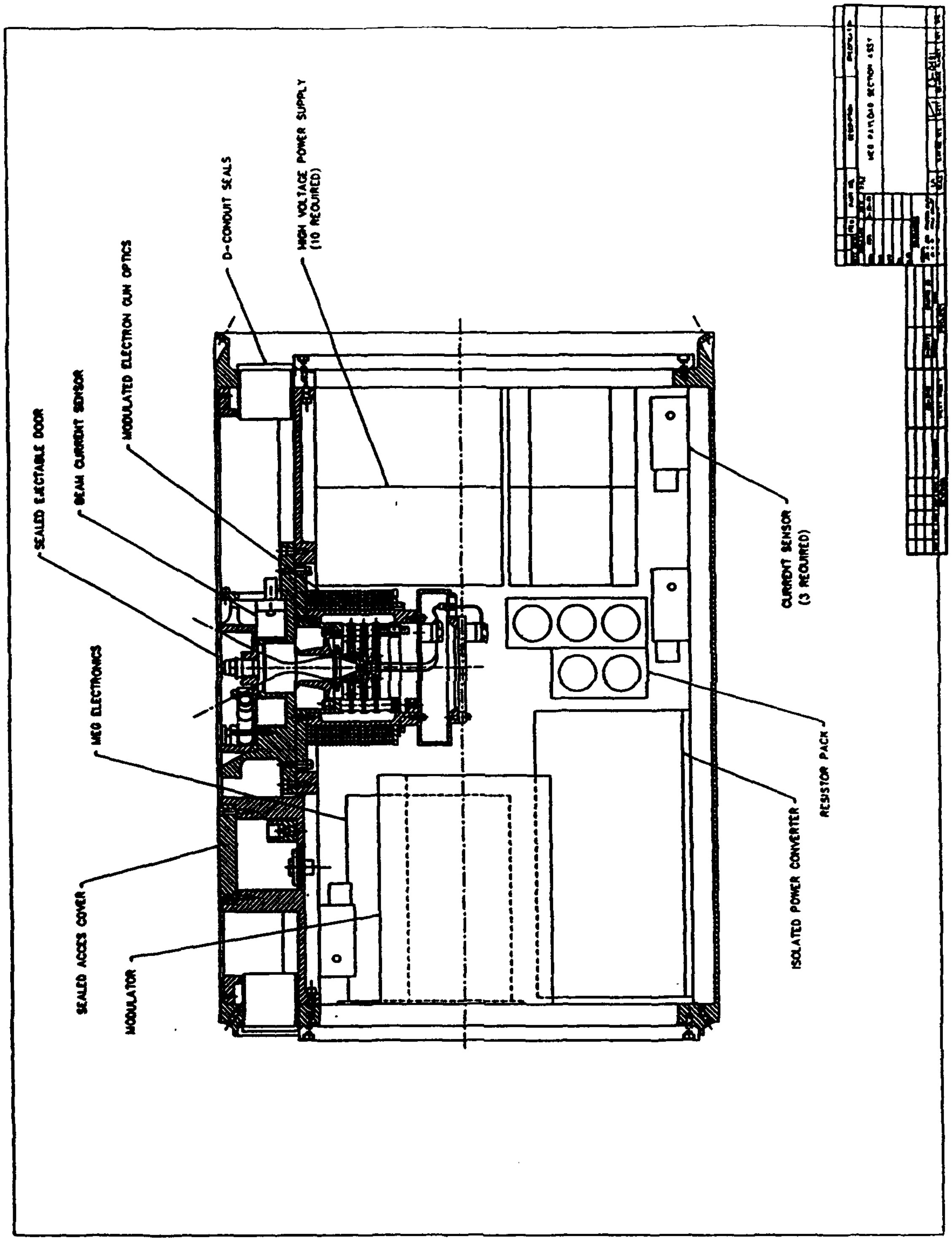


Figure 1. General mechanical configuration of MEG module.

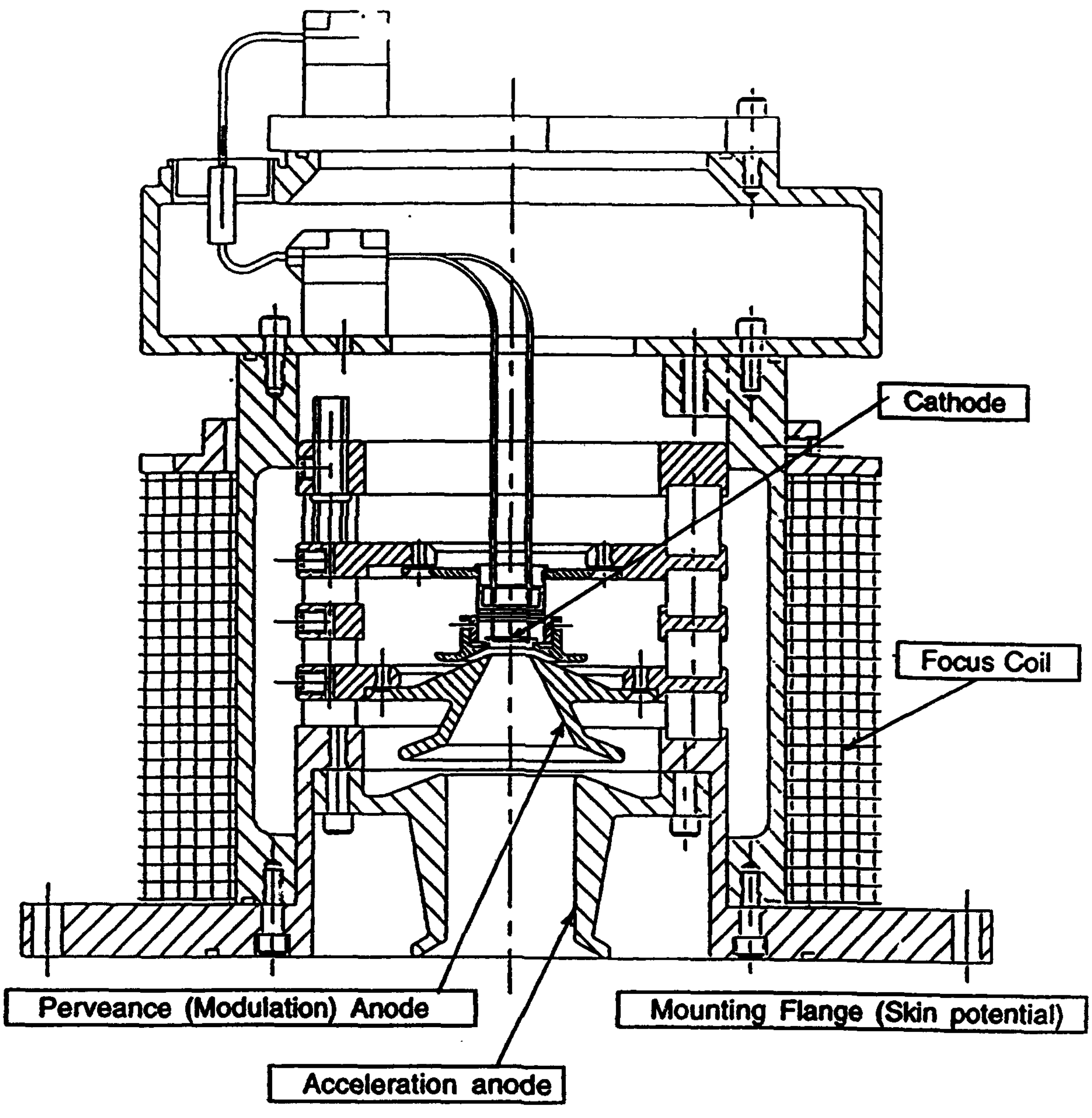


Figure 2. Mechanical details of the electron optical arrangement of the MEG accelerator.

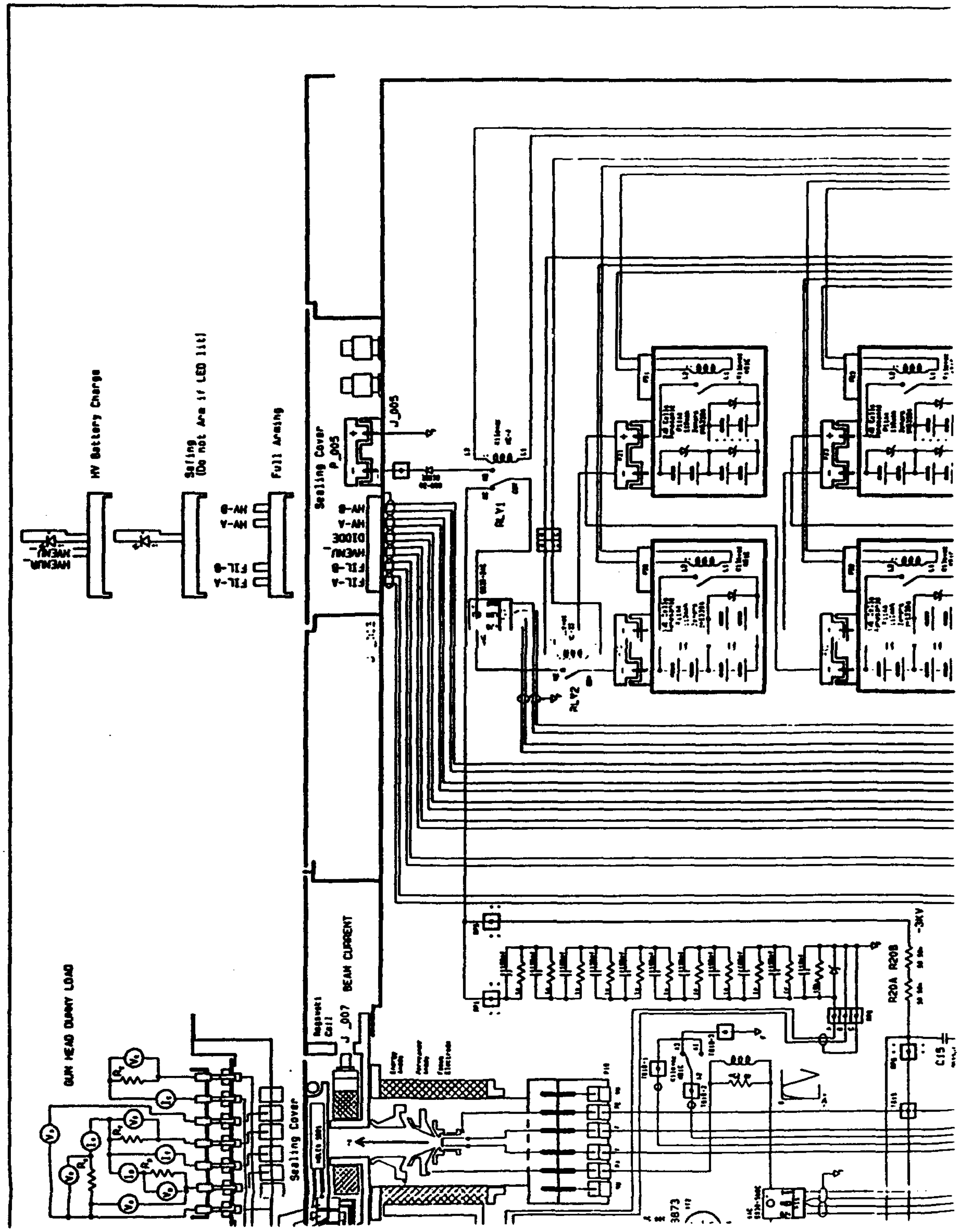


Figure 3A. Electrical schematic of the MEG module.

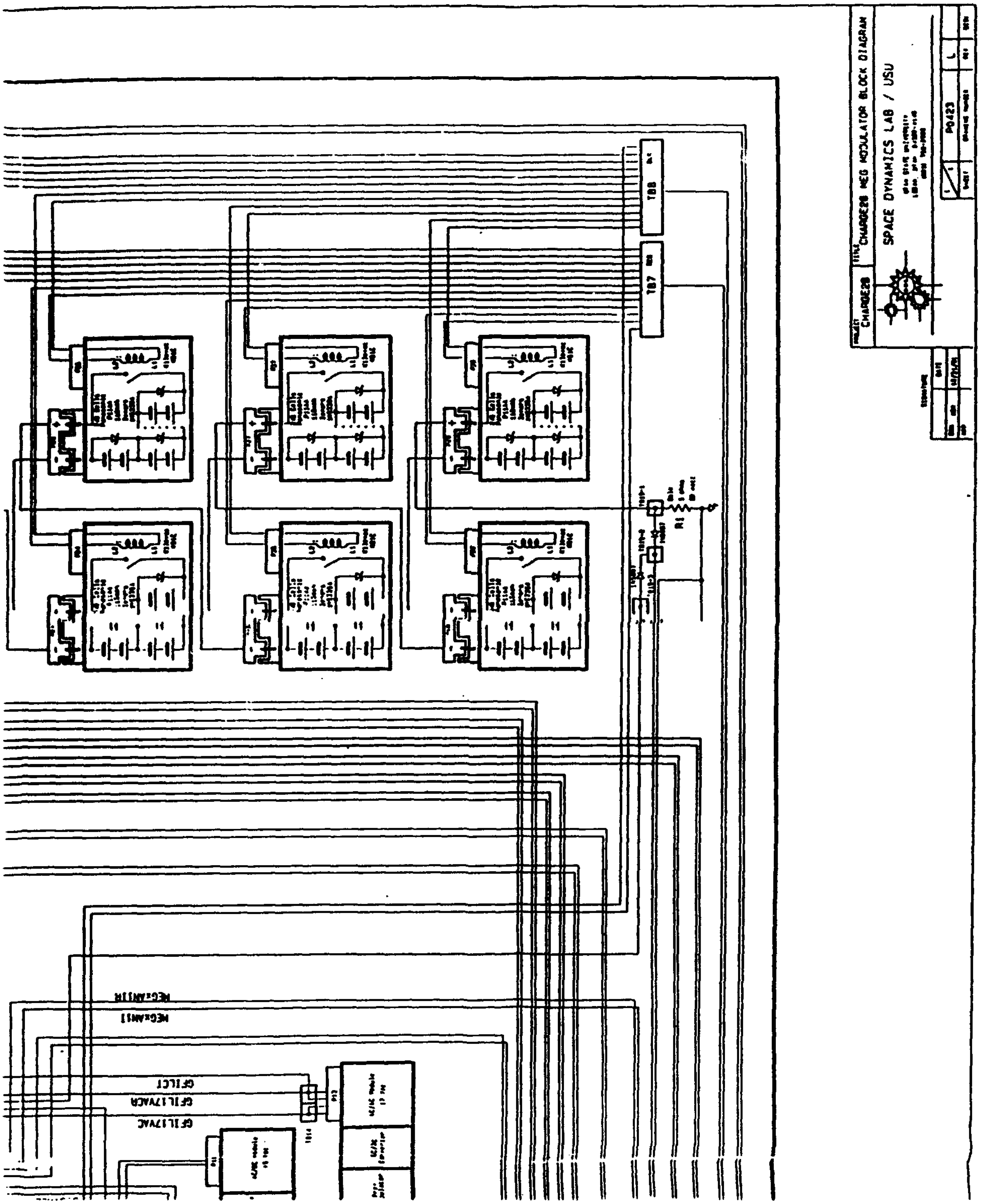


Figure 3B. Electrical schematic of the MEG module.

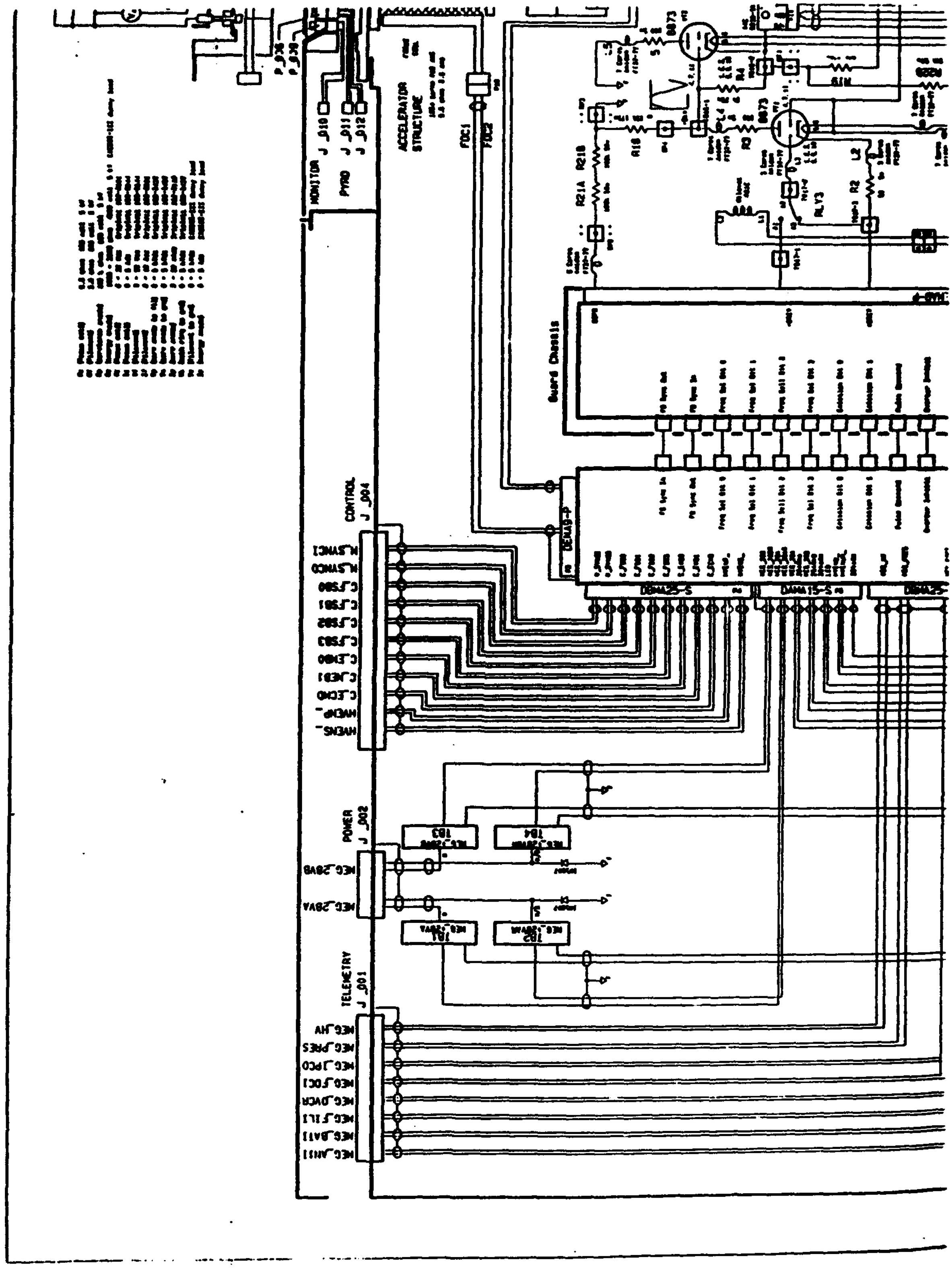


Figure 3C. Electrical schematic of the MEG module.

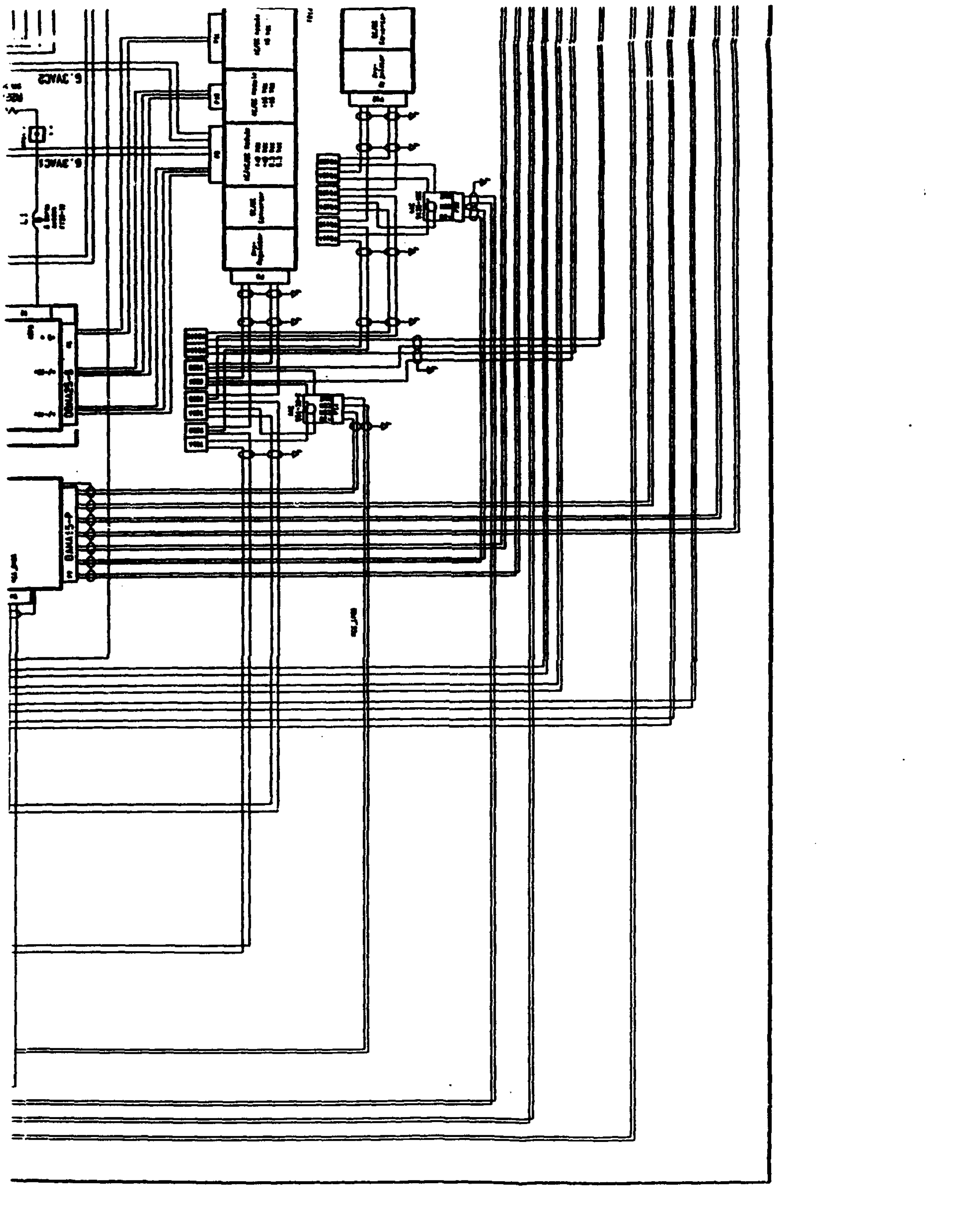


Figure 3D. Electrical schematic of the MEG module.

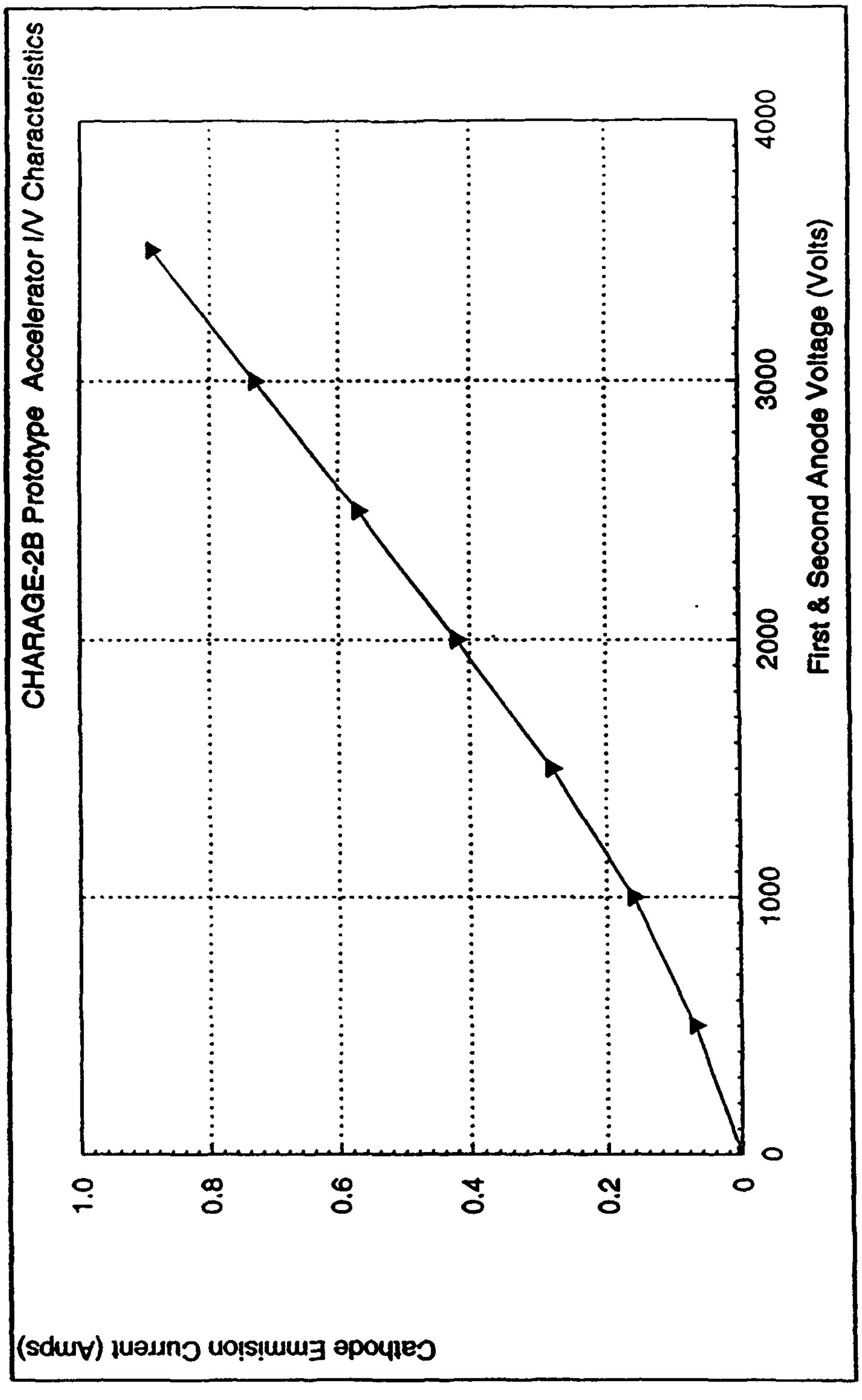
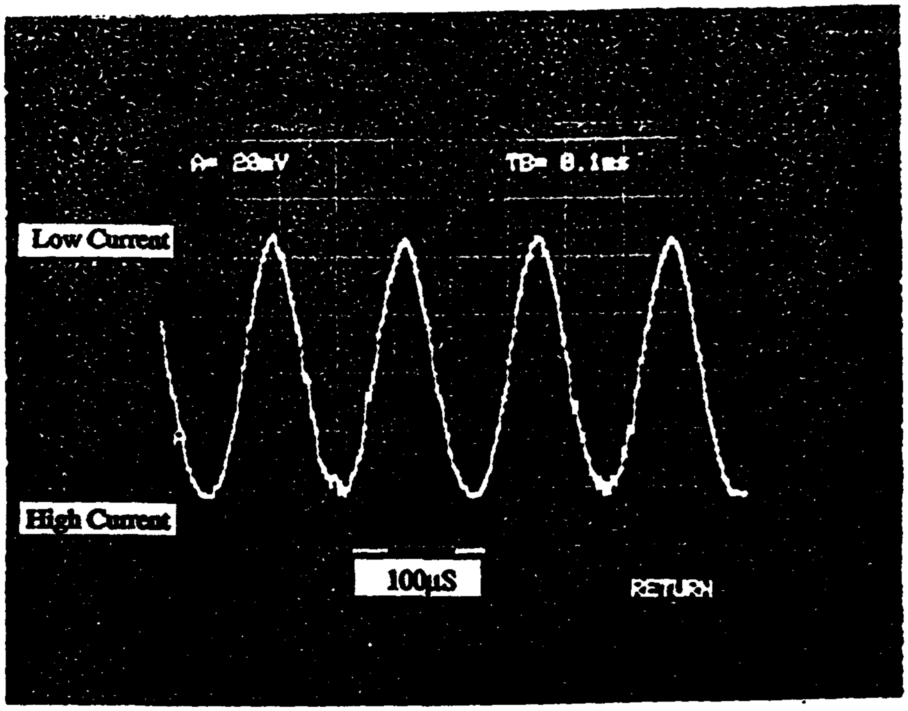
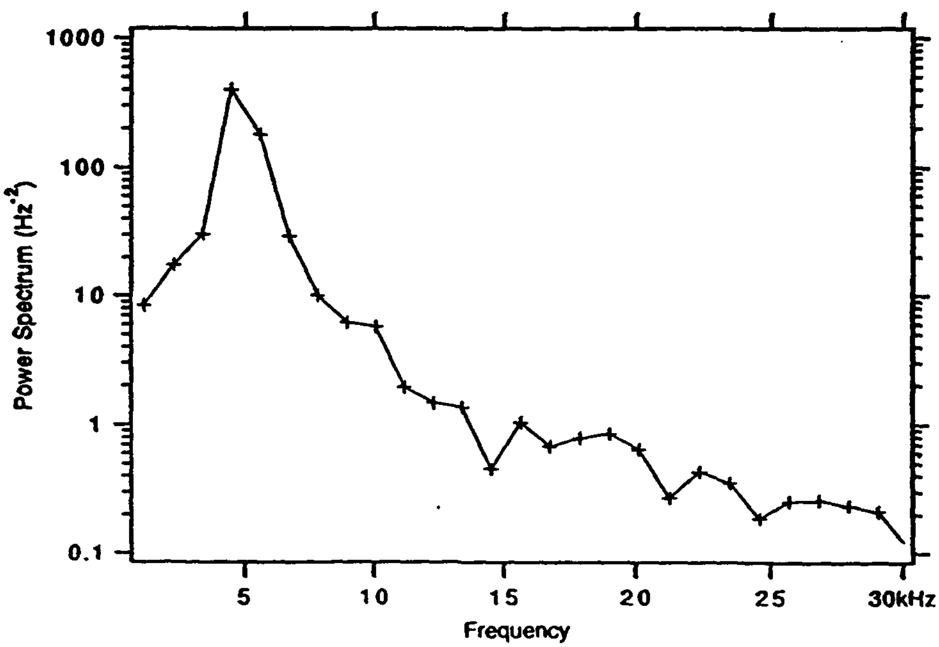


Figure 4. Current - voltage characteristic of a MEG electron accelerator.



(a)



(b)

Figure 5. The upper panel (a) shows the waveform of MEG beam current monitored by a Rogowski coil during a vacuum chamber test. The lower panel (b) shows the spectrum of the waveform in (a).

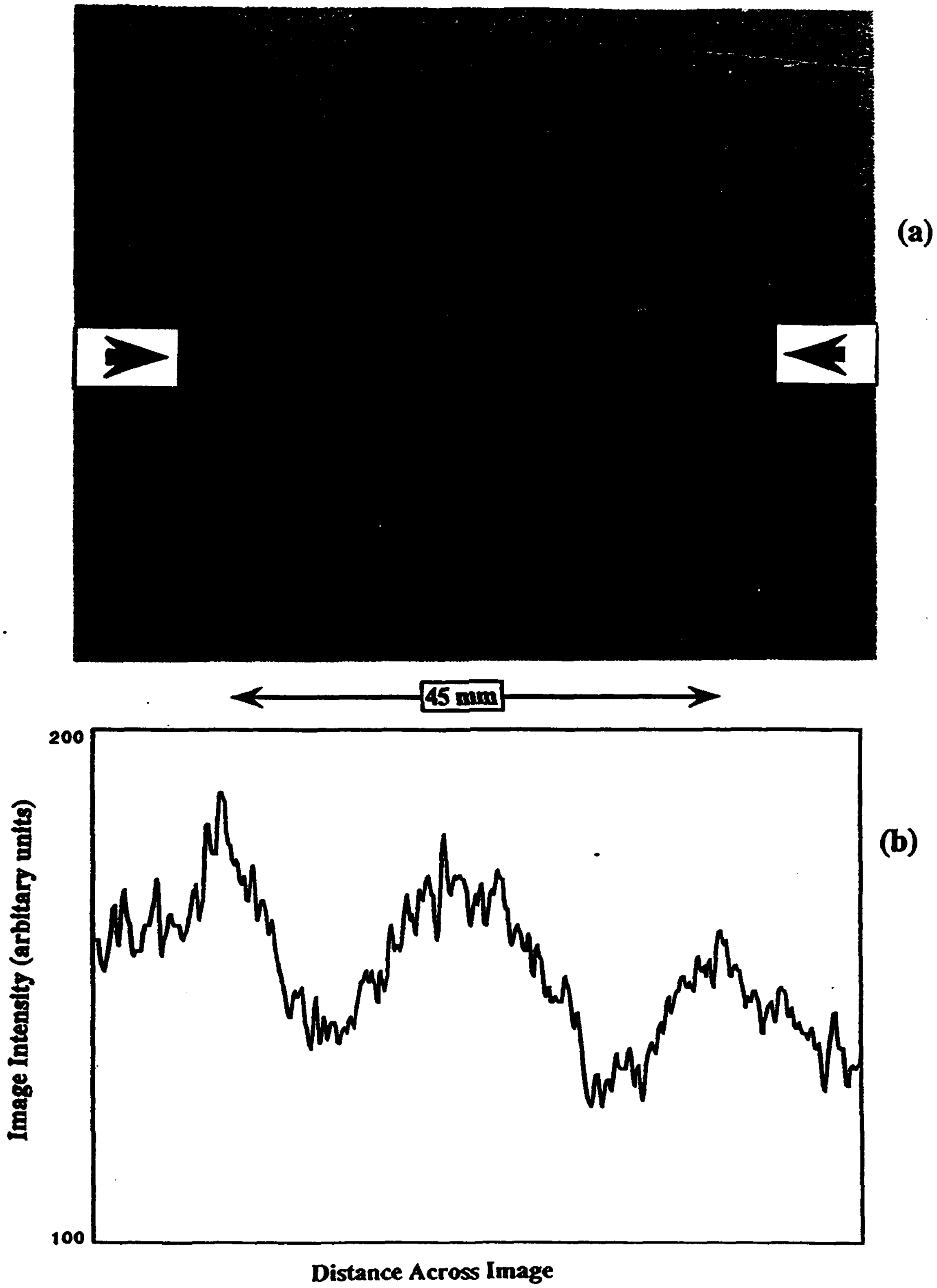


Figure 6. The upper panel (a) shows a photographic image of the discoloration of an aluminum plate in the path of the MEG beam 610 mm from the exit port. The lower panel (b) shows a scan of the image intensity across the center of the beam image.

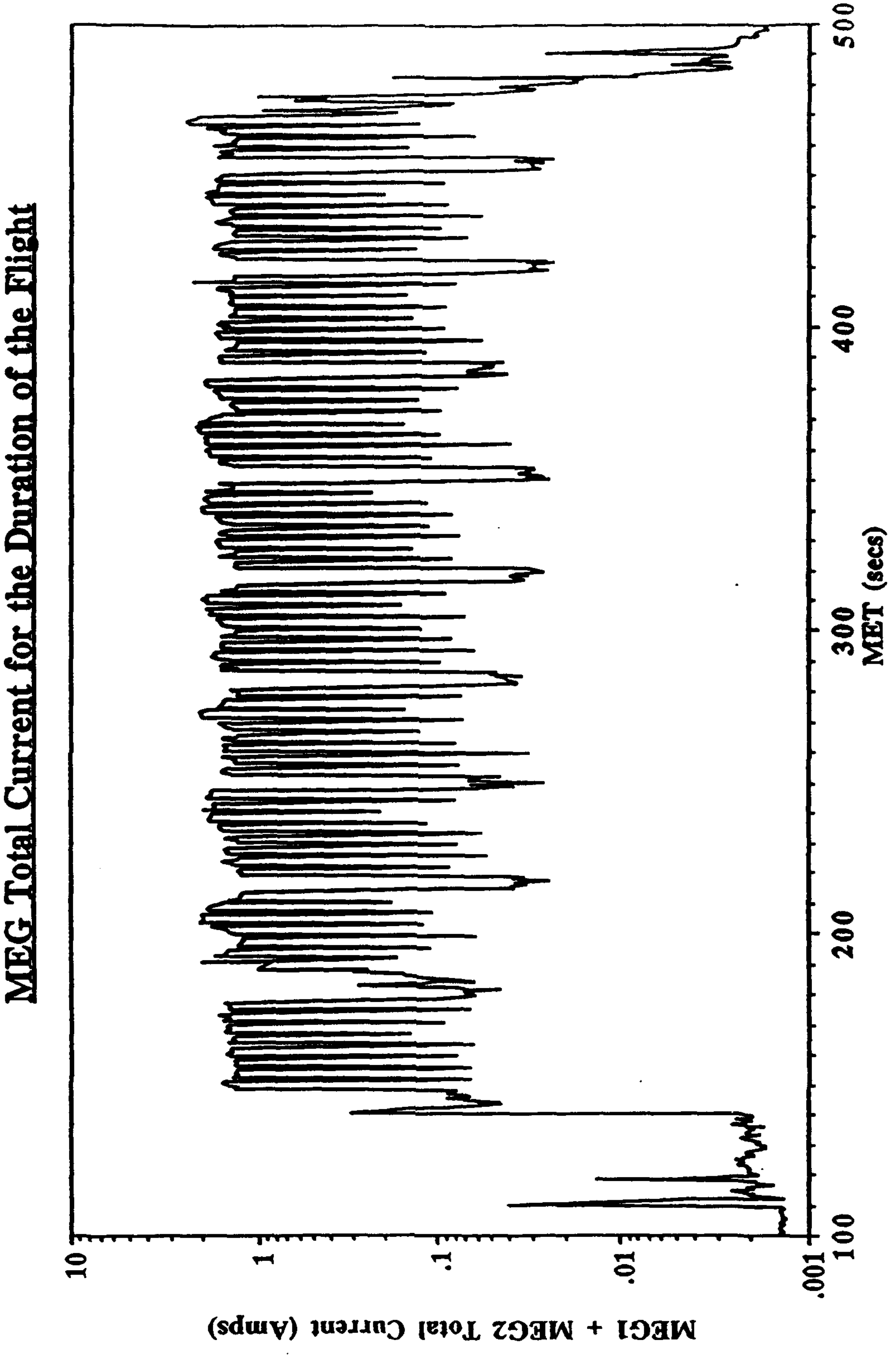


Figure 7. Survey of peak total emitted current from MEG 1 and MEG 2 for the duration of the active portion of the flight.

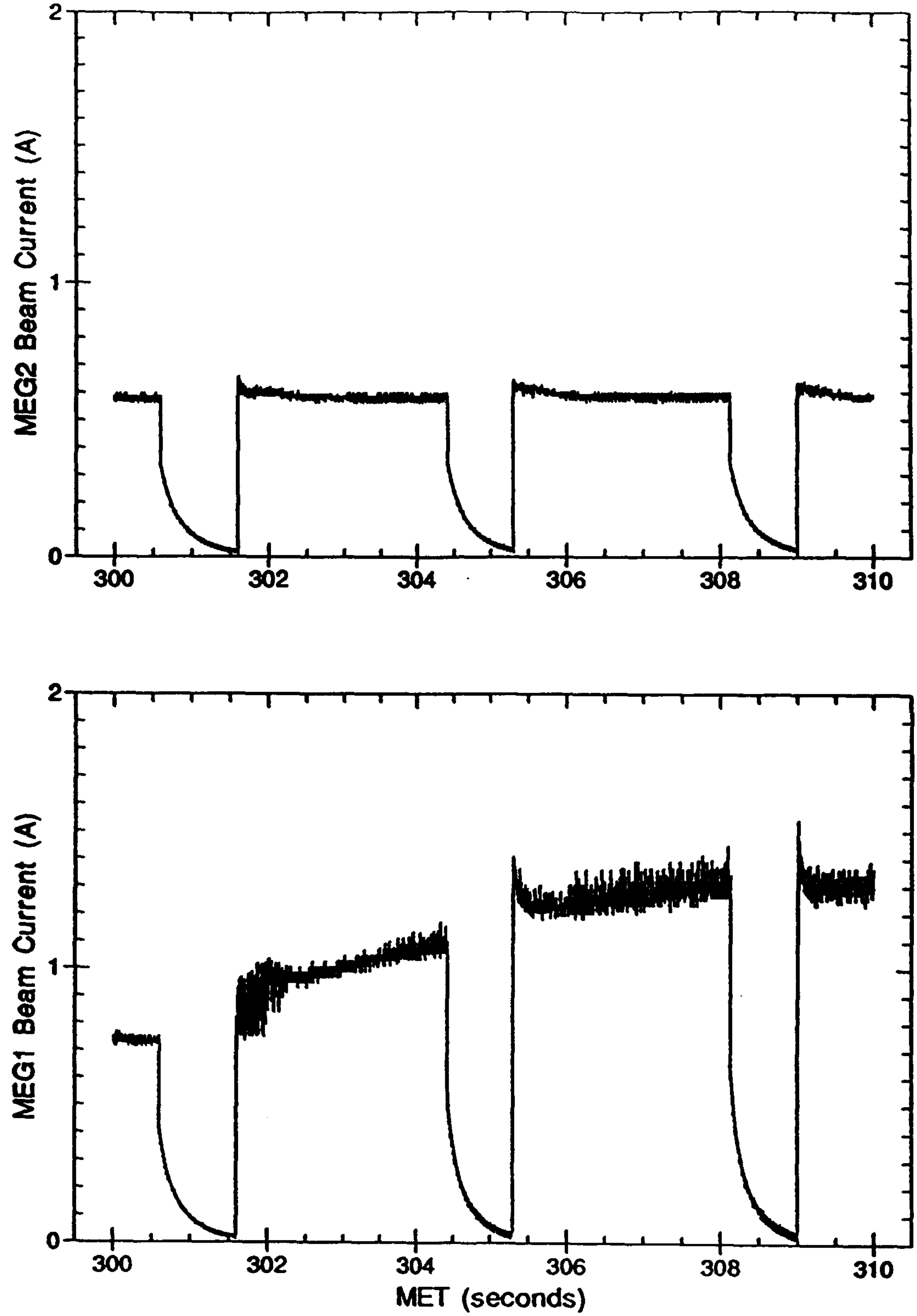


Figure 8. Detail of peak current emitted by MEG 2(upper panel) and MEG 1 (lower panel).

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